Oponentský posudek na disertační práci

Autor: Ing. Yesid Mora Sierra

Název práce: Advanced FPGA-Based Readout Electronics for Strip Detectors

Oponent: doc. RNDr. Peter Kodyš, CSc., ÚČJF MFF UK Praha

Autor v předložené práci zkoumá stripové detektory jako spektroskopická zařízení zdrojů ionizačního záření. Práce má standardní rozsah disertační práce – úvodní strany a seznam použitých symbolů, 95 stran odborného textu, za nimiž následuje literatura, bez příloh. Postrádám seznam publikací autora (asi zahrnutý do literatury) a konkrétnější vymezení podílu autora na problematikách popisovaných v práci.

Práce je členěna do patnácti kapitol včetně úvodu a závěru. V první kapitole je čtenář seznámen s metodami měření ionizačního záření a k tomu určenými detektory. Velice stručně je zmíněna existence plynových a kapalinových detektorů, scintilační detektory a fotodetektory. Dále jsou zmíněny polovodičové detektory a detekční diody a jsou ukázány hlavní důležité rozdíly od plynových detektorů. Druhá kapitola se hlouběji věnuje dvoustranným stripovým detektorům a sběru informace z nich až po digitalizaci zaznamenaného signálu. Úvod do radiační spektroskopie, Comptonovské kamery a využitelnost stripových detektorů je obsahem třetí kapitoly. Vlastnosti stripových sensorů, kapacitní vazby a podobně jsou obsahem 4. části, 5. kapitola popisuje nábojové předzesilovače na sběr náboje ze sensorů s ohledem na vstupní kapacity, co je v 6. kapitole napojené na stručnou analýzu šumu sensorů a předzesilovačů.

Kapitolou 7. začíná cenná experimentálně analytická část předložené práce představením použitých sensoru od norské firmy Sintef a ASICs z BNL včetně jejich základních vlastností. Kapitola 8. představuje první spektroskopickou desku s FPGA autora včetně výsledků testů. Kapitola 9. představuje druhou integrovanou verzi autora zase včetně výsledků testů s prezentací i prvního měření na reálném spektru gama fotonů Am241. Kapitoly 10 a 11 popisují firmware FPGA a software na optimální vyhodnocení signálů ze senzoru. Kapitoly 12, 13 a 14 se věnují základnímu naladění elektroniky, trimmingu kanálů a její kalibraci, výsledkům, stručným komentářům. Hlavní výsledky práce jsou shrnuty v 15. kapitole, autor zde taky uvádí další směry výzkumu směrem k BNL ASIC čipům a aplikaci double sided stripových sensorů.

Z práce vyplývá, že jejím hlavním přínosem je aplikace existujících dostupných čipů na stripové detektory a možnost výroby relativně levného plošného spektrometru ionizačního záření, vhodného do radiačně exponovaného prostředí. Byly vyrobené dvě iterace zařízení a potvrzena jejich funkčnost.

Vlastní přínos disertant v práci kontextově prezentuje v kapitolách 8. až 14. Vlastní publikace autor neuvádí, výsledek je rozhodně zveřejnitelný.

Na základě předložené disertace a dalších dostupných informací jsem nabyl názoru, že disertant významně přispěl k vytvoření funkčního spektrometru na báze stripových detektorů v souladu s vytyčeným cílem v úvodu práce, provedl testy, kalibraci a trimming zařízení, řešení realizoval ve dvou krocích bezpečným způsobem vedoucím k cíli.

Ohledně významu pro obor elektroniky se nemůžu kvalifikovaně vyjádřit.

Práce je napsána vcelku přehledně, úzce související kapitoly mohli být pro přehlednost spojeny, např. části 4. 5. a 6., nebo 10. 11. 12. a 13., naopak, kapitola 14 prezentující výsledky by si zasloužila podrobnější členění. Práce obsahuje experimentální údaje i grafy. Jazykem práce je angličtina na dobré úrovni a občasné jazykové neobratnosti nejsou na úkor srozumitelnosti.

Práci bych vytknul některé nedostatky a v závěru nastínil některé otázky, které mě při studiu práce napadly a autor by je měl zodpovědět:

- VHSIC (Very High Speed Integrated Circuit) zkratka nebyla vysvětlena.
- V seznamu zkratek snad není potřeba uvádět vysvětlení řeckých písmen a prvků periodické tabulky, naopak postrádám seznam obrázků, který by pomohl v orientaci v práci.
- Obr. 41 a jemu podobné nejsou čitelné.
- Číslování obrázků a rovnic není odvozené od kapitoly, co zhoršuje orientaci v textu, v elektronické formě práce není propojení obrázku, rovnic a referencí prolinkováno.
- V druhé kapitole 2.1.1 autor zavádí pojem fake/phantom events, z kontextu textu vychází, že myslí spíš na fake hits a ne events, kdy se rekonstruuje poloha průletu částice na více místech při vysoké occupancy detektoru, obecně autor nerozlišuje v práci event a hit. Je taky otázkou nakolik potřebuje spektroskopie znalost místa průletu částic, nebo ji stačí rozlišit dvě za sebou letící částice, co autor bohužel nezmiňuje. Stejně tak se nabízí na toto téma podrobnější úvaha a analýza, co autor bohužel neuvedl možná i proto, že nerealizoval double sided sensor řešení.
- V druhé kapitole bych ocenil diskusi nebo informaci relace tloušťky sensoru k typu a energii detekovaného záření.
- Na obr. 11 autor zjednodušil situaci, tvar signálu ze sensoru nemá jim ukázaný tvar obdélníku, ale je modifikovaný fyzikou šíření náboje v sensoru i geometrií stripů vnášející indukční a kapacitní vazby do systému, autor tyto efekty v práci částečně diskutoval v pozdějších kapitolách, kapacitní vazby stripových detektorů podrobně rozebral ve 4. části. Bohužel autor nediskutoval tento vliv na měření amplitudy signálu a deformaci informace o změřené energii, její příspěvek k velikosti FWHM, i když tyto efekty pro jím použite velikosti vzorků (do 10 mm délky stripu) jsou zanedbatelné, u používaných až 140 mm dlouhých stripů už tento jev není zanedbatelný. Vytyčení hranic řešení by bylo užitečné pro další pokusy se zvětšováním délky stripů.
- V části 2.2.3 autor nezmiňuje další důležitý efekt vznikající u stripových detektorů s větší mezistripovou kapacitní vazbou – podkmit signálu snižující amplitudu v čase následujícího pulsu, pokud v tu chvíli přijde. Stejně tak neřešil indukci signálu na sousední stripy, snižující potenciál na nich.
- V části 2.2.3 autor ukazuje na obr 12. situaci s dvěma píky na sobě, dál bohužel tento problém nediskutuje, jeho vliv na vlastnosti spektrometru a koincidenci tohoto efektu s nastavením triggeru na identifikaci píků.

- Autor nediskutoval rozdíl ve tvaru pulzu – amplituda i časový průběh – ze sensoru pro elektrony a díry, waiting potenciály a podobně a jejich vliv na měřená spektra.
- Autor nediskutoval vlastnosti sensoru a detekce u krajů, možnosti zmenšení guard ringu, tzv. edge detektory.
- V kapitole 7. autor představil zvolené ASICs z BNL, kde je shaping time od 500 ns. Neuvažoval o rychlejších ASICs dostupných na trhu se shaping time 50 ns a možností vzorkovat měřený pulz až např. 6 měřeními každých 30 ns např. APV25 použitých v experimentu CMS (CERN) a následně pak na Belle II (KEK)?
- Autor ve vlastnostech použitého čipu BNL neuvádí RC odezvovou křivku, ukazující linearitu výstupního signálu vůči vstupnímu.
- Obr. 51 by mohl explicitně upozornit na ALTERA FPGA development kit, který není jinak uveden, schází mi informace o délce použitého propojovacího kabelu a o akceptovatelné maximální délce propojovacího kabelu.
- Obr. 53, 54 a 55 srovnávají teoretickou a změřenou závislost napětí a digitálního výstupu, autor neuvádí, jaké jsou nároky na tuto závislost a její linearitu, není jasné, kde vzal teoretickou závislost a proč je závislost proměřena jen v 6 bodech. Diferenciální plot by vypověděl víc.
- Nerovnoměrnosti mezi jednotlivými kanály (obr. 56) autor přisuzuje hlavně technologickým omezením při výrobě, existují ale i fyzikální omezení fluktuací při depozici implantů u nejmodernějších technologií.
- Obr 57. má Time škálu v sekundách velice nepřehlednou, když ukazuje mikrosekundové jevy, postrádám alespoň horizontální grid umožňující vidět, co autor změřil.
- Kapitola 8 a 9 prezentuje autorem vyvinutý systém včetně testů a výsledků z nich, škoda, že autor lépe nepopsal testovací uspořádání a nepřiložil fotografie z testů.
- Obr. 63 ukazuje spektrum, autor neuvádí podmínky jeho nabrání (vzdálenost od zdroje, vakuum, sensor jaký použil a při jakých podmínkách...).
- Obr 78a ukazuje nerovnoměrnosti v gain jednotlivých čipů ASIC, závislosti byli pravděpodobně získané pomocí interního kalibračního kapacitoru, co může byt zdroj chyby pro trimming, byli testovány kanály na eliminaci této chyby? Jak? (externí generátor, laser, selekce klastru a radioaktivní zdroj,...) Dále v komentáři zmiňuje autor vliv radiačního poškození FEE, pozoroval tento jev a při jakých dávkách?
- Obr 79 uvádí Zirkonium energii 15.74 keV, v literatuře se uvádí taky 15.78+17.67 keV (~10:1, Kalfa1:Kbeta1) [http://www.xrfresearch.com/xrf-spectrum-zirconium], takže proti tvrzení autora by zde mohli být i dva píky.
- Je škoda, že autor používal na demonstraci kroků kalibrace různé zdroje záření, není tak možné posoudit úspěšnost jeho kalibrace, na demonstraci je pak dobry Obr 86 a 87.
- Obrázky z ROOT mají matoucí informace v pravém horním rohu o Entries, RMS a Mean, mají zbytečně ponechané rámečky z ROOT.
- Obr. 84 postrádá y škálu.

- K závěru kapitoly 14 je možné připomenout možnost omezení geometrického vlivu na energii alfa částic a je možné umístit měření do vakua na eliminaci vlivu vzduchu, spektrum pak bude zaostřené.
- Není úplně pravda, že pixelové detektory nutně neumožňují umístění ASICs mimo a potřebují bump-bonding, viz řešení na Belle II (KEK).

Otázky k zodpovězení:

1. Proč se liší spektrum Zr na Obr. 79 a 86?
2. Autor prezentuje elektroniku a testy jen na single side křemíkových sensorech, je možné provádět testy na jeho zařízení i na doublesided sensorech, které uváděl v úvodních kapitolách?
3. Autor uvádí jako základní výhodu popisovaného řešení jeho využití v experimentech s omezeným rozpočtem a potřebou detekce velkou plochou, může vyjmenovat některé příklady?
4. Jaké byly očekávatelné single events efekty v ASICs v radiačním prostředí – jejich četnost, jak odhadnete životnost sensoru ve srovnání se životností readout ASICs? Jakou roli může sehrát stínění ASICs a jaké by navrhl jeho materiálové složení a prostorové uspořádání?
5. Pokud výsledky prezentované v práci autor publikoval, prosím o uvedení seznamu publikací, v práci nejsou dostatečně zdůrazněny.

Přes uvedené nedostatky se domnívám, že předložená práce přesvědčivě dokumentuje disertantův přínos ke studované problematice, splnění vytyčeného cíle průzkumu schopností stripových detektorů jako spektroskopických zařízení pro zdroje ionizačního záření a jeho schopnost samostatně vědecky pracovat. Práci doporučuji uznat jako disertační a autorovi po zodpovědění otázek a jejím obhájení přiznání titulu PhD.

1. srpna 2019 doc. RNDr. Peter Kodyš, CSc.

The report on the thesis titled "Advanced FPGA-based readout electronics for strip detectors" by Yesid Mora Sierra

a) Importance of the thesis for the field

Particle detectors are essential for particle physics as well as other areas of science and technology. Semiconductor detectors collecting charges produced in the depletion regions of reverse-biased diodes have a number of advantages over other types of detectors due to favorable electrical and mechanical properties of semiconductors and due to their easy natural interfacing with semiconductor electronics. Among them, pixel and strip detectors are the most common with the pixel detectors more common than the strip detectors. As the two kinds of detectors have complementary virtues and problems and pixel detectors and their supporting electronics are more developed, a further development of strip detectors and their supporting electronics, which is the topic of the present thesis, is of utmost importance in the field of particle detectors.

b) The methods used and reaching of the goal

Yesid has reasonably decided to develop the supporting electronics for a 128-channel strip detector in two steps. First, he used a commercial ALTERA FPGA development kit to control the detector with four ASICs and other electronic components, so that he could familiarize himself with the operation of the detector itself as well as the electronics, such as the different modes of the ASICs, the optimum values for the thresholds for noise elimination, of energy ranges and shaping times, and the delays caused by various components. Second, he simplified the FPGA-based electronics and placed it all on the same PCB as the detector with the ASICs without any connecting wires. That way he could reach the goal of equalizing the baselines of the four ASICs, reducing the noise, and calibration both internally and with the use of radiation sources with known energies of the emitted particles.

c) Results of the thesis and the original specific contribution of the author

The main results of the thesis are a functional electronic system controlling the strip detector and its successful calibration by alpha particles emitted by Pu, Am, and Cm to the precision allowed by the extended size of the source as well as of the detector as mainly evidenced by the energy histograms before and after the calibration. All these results constitute the author's original contribution.

d) Formal structure and language level

The thesis has a clear structure. The first three chapters discuss particle detectors in general with a special focus on strip detectors and their supporting electronics. Features of strip detectors are further discussed in chapters 5 through 7. The two hardware versions are described in chapters 8 and 9. The controlling firmware and software are then described in chapters 10 and 11. Measurements performed with the system are presented and discussed in chapters 12 through 14, and the conclusions are given in chapter 15. The thesis is internally consistent and well written. I have only found minor typos and grammatical errors that I am listing in the Appendix together with suggestions for possibly clearer formulations and more detailed explanations for readers like me who are not experts in the field.

e) Publications

Yesid has co-authored 8 papers published in impacted journals, 2 papers that are under review, and contributions to various conference proceedings as he has presented his results at conferences. I consider his publications sufficient.

f) A clear statement of recommendation of the thesis for a defense

I recommend the thesis for a defense for which I have the following three questions:

1. On p. 20 you wrote "When using small peaking times the noise is dominated by the white voltage noise component, so it decreases with peaking time. At larger peaking times the noise is dominated by the 1/f component, whose contribution is independent of peaking time [5]." I would expect it the other way around, the white noise independent of time and 1/f dependent on time, but actually increasing with time. Why is it this way? Why does shot noise increase with time in the next sentence?
2. On p. 85, what are the symbols on the right-hand side of equation 17?
3. What new physical phenomena in particle physics have been studied or are going to be studied with the strip detector controlled by your electronics?

In Plzeň, August 29, 2019 Šimon Kos

Attachment: list of minor typographic and grammatical errors, and suggestions for clearer formulations and explanations

p. III

•"His guidance has helped me in all the time of research" **during the whole time of research?**

•"I would like to thank the Institute of Experimental and Applied Physics IEAP-CTU, and to its director Doc. Ivan Štekl, " **and its director? Also further in the text.**

•"for providing me with very useful advices during" **advice should be singular?**

•"My sincere thanks also goes to..." **go to?**

•"clearing up of my doubts" **clearing up my doubts?**

p. V

•"Hybrid pixel detectors, latest development stage of semiconductor detectors, due to their high cost per area" **the latest development? Per unit area? What makes the pixel detectors hybrid?**

•"where it can be shielded from primary irradiation easily. " **From the primary?**

•"no mentionable heat transfer between sensor and ASIC" **the sensor?**

•"the sensor or ASICs can simply be exchanged. " **Replaced?**

•"it was still obtained a system threshold level of 3 keV" **a system threshold level of 3keV was still obtained?**

p. VII

•in the list of symbols, perhaps you could assume people know the symbols for chemical elements and for units? Would alphabetical ordering be more useful?

p. 1

•"Given the previously mentioned limitations associated to pixel detectors, " **associated with?**

•"applications were covering big areas is imperative and where price of using pixel detectors constitute a strong limitation. " **Both where? An imperative? Constitutes?**

•"as a potential replacement of pixel detectors" **replacement for?**

•"Later on, an overlook of the strip-based systems developed in this thesis is provided, " **overview?**

p. 3

•"radiation passing through a gas can ionize the gas molecules and then produce charge pairs" **and thereby produce?**

•"the charges moving generate an electric pulse" **the moving charges?**

•"From all the Gas Filled Detectors, " **Among?**

•"The term ionization chamber has being used for the type of detectors using as principle of operation the collection of ion pairs from gases" **has been? as the principle?**

p. 4

•"The term ion pair refers specifically to a positive ion and a free electron generated after a neutral molecule is ionized" **same as charge pair so far?**

•"Nevertheless, in liquids the energy needed to create a charge pair doesn' t depend on the type of liquid as it happens in gases, but, since the energy states in liquid state are quite different from those in gaseous state the process of charge pair production is more complicated in liquids" **Why doesn't the energy depend on the kind of liquid if the process is more complicated? The liquid state, the gaseous state?**

•"Among the benefits of using liquids instead of gases are the possibility of obtaining more charge pairs for the same amount of energy deposited, and higher total deposited energy per unit path due to their higher molecular density, however, higher density means higher spatial proximity of molecules which increases the recombination probability of charges. " **Semicolon before however? Also somewhere else in the text.**

•"There it is used liquefied argon as mean of detection in large area detectors" **there liquefied argon is used as a means of detection? Also elsewhere in the text.**

•"Liquid Filled Detectors can be used as scintillation detectors using liquid xenon to produce light when its molecules are excited by the incident radiation" **does xenon form molecules?**

p. 5

•"when the atoms of incident radiation interact with the atoms of the scintillation material, they transfer part of their energy to the atoms, exciting them and going into short lived excited states. " **is the incident radiation made out of atoms? What goes into excited states?**

•"as shown if figure 2" **in figure?**

•"The indirect detection mechanism has the disadvantage of need a much more larger energy to produce one photoelectron" **need of a much larger energy?**

•"Although the efficiency of a typical scintillation material to emit photons after the interaction with ionizing radiation is relatively low (10% to 15%), implying that a high percentage of the scintillation photons are wasted away" **or not even produced?**

•"when the scintillation detectors are used in low field environment this is still one of the most problematic things" **a missing comma?**

•"have higher atomic number than organic scintillators" **article?**

•"when it is needed high stopping power" **when a high stopping power is needed? A similar construction also elsewhere in the text.**

p. 6

•"due to photoelectric effect. " **Article?**

•"Photomultipliers with semi-transparent photocathode are commonly used." Plural or an article?
•"deposited to the interior surface" deposited on or onto?
•"the conversion photon" the conversion of a photon?
•"As it was mentioned before" as was? Also elsewhere in the text.
•"a metallic structure called dynode" the dynode? Also elsewhere in the text.
p. 7
•"A photodiode consist of" consists? Also elsewhere in the text.
•where is the 'i-layer' in figure 4? Also why the asymmetry that there is light n doping but no light p doping? Also in the next section on the reverse-biased diode. Because of a higher mobility of electrons than holes stated on p. 9?
•"A bias voltage is applied to the n silicon layer or 'i-layer' to deplete the diode." Bias relative to which part?
p. 8
•"reverse-biased diode is a very important part" component?
•"due to its devoid of mobile carriers" due to it being devoid?
•"in order of micrometres" on the order of?
p. 9
•"can be either metal-semiconductor contacts, p-n diode junctions" or p-n diode junctions?
•"unique properties compared to other type of detectors" types?
•"Here there is a comparison" Here is?
•"High density of Silicon (2.33 g/cm3)" is this a high density? Why is mass density important for a detector performance?
•"Electrons and holes can move almost freely despite of its high material density, then the charge can be rapidly collected" therefore?
•"appropriate for X-ray and almost infrared measurements" almost infrared means red?
•"their used is limited for radiation detection where" use?
p. 10
•"On figure 6" in? also elsewhere in the text.
•"a guard ring which is mean to isolate the wafer edge from the active region." meant? Also elsewhere in the text. Where is the wafer edge? Is the diode circular that the guard forms a ring?
•"The bulk material is made of lightly doped n silicon, and forms a junction with a highly doped p+ layer. The depletion region is created predominantly into the bulk. The back contact is made of highly doped n+ silicon, the same kind as the bulk" Is this the opposite of figure 4 on p. 7? Where else could the depletion region be if not in the bulk?
p. 11
•what is meant by single- and double-sided detector in Figure 7?
p. 12
•"In double-sided strip detectors, the strips on both sides are usually orthogonal to each other," is the bottom in Figure 8 the top rotated by 90 degrees? What are the p-stops on the top and why are they not sticking out over the p+ implant on the bottom?
•"Right angles are problematic when used in experiments with high occupancy rates due to the increase of fake or 'phantom' events." Why are there more fake events for the right angles?
•"crossed strips of one side respect to the other" with respect? Also elsewhere in the text.
•"since the events are produce" produced? Also elsewhere in the text.
•"On figure 8 it is also possible to see guard rings, placed there to reduce the possibility of electrical break down." How do they do it?
p. 13
•"Probably the main advantage is shielding of the readout electronics from dark current, which can lead to pedestal shifts, a reduction of the dynamic range, and may even drive the electronics into saturation" what are pedestal shifts and the dynamic range?
•"In order to implement an AC coupled detector, a coupling capacitor has to be added to each channel." Why and what is the coupling capacitor? How is it different from figure 8?
•Figure 9: what is p-spray?
p. 14
•"This low-level signal is integrated in a preamplifier," what is a preamplifier as opposed to an amplifier?
•"An important parameter to take into account is the total capacitance in parallel with the input, which is composed by the detector's capacitance and input capacitance of the amplifier." why is this a capacitance parallel to the input rather than the capacitance of the input? How does it affect the signal-to-noise ratio as stated in the next sentence? Due to a higher voltage for the same charge if the capacitance is lower?
p. 15
•"As we are not interested into measure just one pulse" interested in the measurement of?
p. 16
•"When the pulse shape doesn't change but only the peak amplitude," does?
p. 17
•"monotonically increasing thresholds, provided by a resistor voltage divider" the threshold is given by the voltage on the lower electrode of each comparator or in some other way?
•"speed and resolution are opposing parameters and there must be a trade-off according to the application" there must be a compromise because there is a trade-off?

p. 18

•"it can be referred to as the general term" by?

p. 19

•"illustrated in the figure 16" in figure 16?

•"It is important to mention that if the energy resolution is smaller, the possibility to distinguish between two radiations whose energies lie near each other is higher." lower?

•"There are several sources of fluctuation in the response of detectors that degrade the energy resolution. These include any drift of the operating characteristics of the detector during the measurements," is drift a fluctuation?

p. 20

•"In the case of localized charge deposition (γ-gamma and X-rays of < 30 keV in silicon)," why is the charge deposition delocalized for higher energies? One gamma is enough as the notation?

•"Figure 17 shows results of the noise vs. peaking time in a strip detector." What is the equivalent noise charge? How is it measured? Also in chapter 6.

•"the lower capacitance generates lower noise." Why?

p. 22

•Figure 19 is a view from the top?

•"and it works better than other materials in terms of the 'Doppler broadening' effect." Why?

p. 23

•"For example, the coupling capacitance has a direct influence on the signal strength, and the interstrip and body capacitances affect the noise
level of the signals." What is coupling and body capacitances, and why and which way do they affect the two parts of the signal-to-noise ratio?

•"Additionally, lowering of the interstrip capacitance is achievable by p-blocking strips." How? Do they somehow decrease the voltage?

•"In AC coupled detectors, wide strips increase the coupling capacitance between the implant and the metal." Refer back to figure 8 or 9?

•"the resistence of the metal strip, which has to be minimized in order to reduce the dispersion of the signal" why?

•"Typical strip pitches range from twenty to few hundred micrometres." A few? Also elsewhere in the text.

•"The charge collected at the interpolated strips is divided between the two neighbouring readout channels according to the relative position. This can be accomplished by resistive or capacitive division." Interpolated strips are those in between the collection ones? If so, how do we collect the charge from them? How can we choose between the resistive and the capacitive division?

•"To keep small loses," losses?

p. 24

•"Other features to take into account are efficiency and noise signal. These parameters may put limits to capacitive load from the detector to the readout electronics" how do they put these limits?

•why the frequency dependence of the capacitance in Fig. 21-23? Decrease because there is not enough time for the capacitor to charge? But that would be given by the RC constant and not just the capacitances, as indicated on top of p. 25?

p. 26

•"the total capacitance for p-side silicon detectors with different strip width but constant strip pitch of 50um, as function of the ratio strip width over pitch w/p." what are p-side detectors? Is the capacitance a function of just this ratio when both w and p change?

p. 27

•"The total strip capacitance has a key role" plays? Also elsewhere in the text.

•"The metal strip of each channel has finite resistance (e.g. 30Ω/cm for 10um width) and does not contribute to the noise of the fast amplifier" finite here means small?

p. 28

•is the amplifier here the same as the preamplifier in section 2.2.2? Why is it not called the preamplifier here?

•"C_i represents the dynamic input capacitance." What is a dynamic capacitance?

•"When mobile charge carriers move towards the electrodes, they change the induced charge on the sensor electrodes." Same electrodes?

•"Supposing that the amplifier has a small input resistance," say more clearly that this is the explanation for why the input resistance needs to be high? Input resistance is parallel to the input capacitance?

•"as seen on equation 1" in?

•"However, if it is used a charge sensitive preamplifier, it would overcome this problem providing an output signal amplitude independent of the input capacitance" of both capacitances, esp. of the other capacitance that can be changing?

•"Figure 26 shows a circuit configuration of a charge sensitive preamplifier." In the caption to Fig. 26 it says amplifier. Is there a difference?

p. 29

•what is ω_0 in equation (2)? Is it the same as just ω at the end of the paragraph? Units should be upright as elsewhere in the text?

•"The amplifier response can be slower than the duration of the current pulse from the sensor," how so?

•what is the gain bandwidth?

•"Typical input impedance of charge sensitive amplifiers in strip detectors systems is of order KΩ." On the order of?

•"the capacitance of each strip to the backplane" **back plate?**

•"On the other hand, if the input impedance of the amplifier is low compared to the interstrip impedance, almost all the charge will flow into the amplifier of one channel," **it could still flow from more than one channel if the charge is induced on more than one channel due to close strip arrangement (cf. third paragraph on p. 11)?**

p. 31

•"It is common to use noise current sources to represent resistors shunting the input, and noise voltage sources to represent resistors in series with the input" **why?**

•"it is a must to understand its effect over the signal to noise ratio" **on?**

p. 32

•"at short shaping times the voltage noise dominates in the signals, whereas at long shaping times the current noise dominates." **Why? What gives the dependence of the current and voltage noise on the shaping time?**

p. 33

•"whilst figure 31 shows a zoomed in image of its bottom left corner." **So the guard ring is not round after all, so it is not really a ring? Scales would be nice in both figures.**

•"It was fabricated in a 300 μm thick Silicon wafer but its active area was reduced to 200 μm to provide the possibility to fill the etched area with any kind of convertor for the detection of non-charged particles." **What converter was placed there?**

•"The bonding pad openings of the detector are 100x50 μm2 and it contains frontal side contacts for the bias voltage" **they? Where are they in the figures?**

•"Despite the size of the detector is just 14x14 mm2" **being?**

p. 34

•"using discrete components cannot be considered as realistic. A better solution is to contain these sensitive electronics into a single chip that can deliver already processed data through standard digital signals and/or amplified analog signals." **The components in the chip are not discrete?**

•"This is the case of the ASICs used in this thesis" **for?**

p. 35

•"fully compensated continuous reset" **what is it?**

•"5th order shaping amplifier with complex conjugate poles" **what is it?**

•"a band-gap referenced baseline stabilizer" **what is it?**

•**where are the DACs in figure 33? Or is this just the channel and the DACs are outside the channels?**

•"one to coarsely control the threshold level and the other to control the amplitude of the test pulse applied to each channel through the test capacitors." **The other controls finely?**

•"Each channel has a 4-bit DAC for fine equalization." **Or is this the fine part? Are these different DACs?**

•"Additionally, the polarity to which the channels are sensitive to can be chosen (positive or negative)" **twice to?**

p. 36

•"the ASIC is configured by writing its configuration register" **what goes into this register and what determines its length? What do the other signals in figure 34 do? Time is going from the right to the left? The EN signal has different shapes in the different figures?**

•"The signal generated in each channel by the electronics due to the charge, must be higher than the threshold in order to be taken into account by the peak detector." **Where do I see that in figure 35?**

•"On the contrary, the event is simply discarded." **Otherwise?**

p. 37

•**where is the signal in figure 35?**

•**what is D0:D4?**

•"The reading process is made in sparsified mode, which means channel by channel [16]." **How else could it be done?**

p. 38

•**is there a local threshold too?**

•"to work out of the noise range" **outside?**

•"The threshold value, which is an analog global value for all the channels of a particular ASIC, is produced internally by means of a Digital to Analog converter DAC" **meaning it is produced from a digital number?**

•**why does the DAC have a different baseline from the channel's baseline?**

•**where does the value of NthDAC come from?**

•**is BLthDAC=189mV and DACthstep=1.95mV here?**

•**why a different structure of the index of V and N in (4)?**

p. 39

•"where NchtrimDAC is the digital value set for a particular channel' s DAC" **where does this value come from? From the calibration to be described later?**

•**again, is DACtrimstep=3.5meV here?**

•"the trim DAC logic of every channel works inversely to the global threshold DAC" **why is that? Is it related to the subtraction in equation (5) as minus times minus is plus? In that case the base line should really be BLthDAC-15DACtrimstep?**

•**VtheffectiveCHn in figure 38 is the same as Vthch in equation (5)? If so then why the difference in the notation?**

•"The trimming DAC cannot be considered as a fine tuning for a channel' s threshold since it has a bigger step compared to the global threshold DAC' s," **why does it have a bigger step?**

•"Three different energy ranges are available in the ASIC." **How big is the charge per, say, 1MeV?**

p. 40

•"Eventhough the maximum energy range of the ASIC can be used always," **Even though? Also elsewhere in the text.**

•"it is recommended to choose the range according the energy of the particles of interest;" **according to?**
•"the reason is that the maximum output signal from the ASIC (2V) will be divided by a smaller energy range, giving more precise values." **Will be used for?**
•"On the other hand, if heavy particles are wanted (highier than 1.57MeV), it is necessary to use the lower gain, otherwise, the energy of the particles will saturate the ASIC' s channels." **higher? Also elsewhere in the text. Semicolon before otherwise? The lowest gain?**
•"Longer shaping time can reduce the noise of the measurement when there is not parallel noise contribution to the ASIC' s channels" **what if there is a parallel noise contribution and what is it?**
•"choosing the shortest shaping time saves hours of measurement time, and even more important, reduces the human exposure to radiation." **Importantly?**
•"The ASIC provides two analog output signals: Peak Detector output (PD) and Analog Monitor Output (OA)." **Why the abbreviation OA?**
•"the second one contains information about internal features of the readout channel" **what is that? Say that they will be described later?**

p. 41

•**in figure 39, what gives the start and end of each PD signal in the graph on the right?**
•**In figure 40, what are the other symbols 5:1, 5:2, DD1:DD0, C4:C0, SBM?**

p. 42

•"One more important point regarding the analog output signals is the settling time." **Would it be useful to define it?**
•**Could figures 41 and 42, 46 to 48, and 66 and 67 be made more legible?**
•"Even though there is the possibility to activate an analog output buffer for each analog signal," **what would this be good for?**

p. 43

•"According to the simulation, a load higher than 4KΩ provides an error less than 1% in the amplitude of the analog signal." **An increasing load gives an increasing error?**
•"active voltage shifter with unitary gain" **what is a unitary gain?**
•"adecuate impedance loading" **adequate?**

p. 44

•**where is figure 43 in the big scheme? Where is it connected to the ASIC in figure 33?**
•"Theoretically, the first 250mV of the signal represents the channel' s baseline" **where does the value 250mV come from?**
•"Every value contained in the ASIC' s analog memory" **is that every value of VPD?**
•"As it is not likely to have a commercial ADC using a similar input voltage range, it was necessary to include a signal conditioning circuit in the design." **why is it not likely? Or why did they choose such a range for which it is unlikely? Should this sentence be placed earlier as a motivation for having the signal conditioning circuit at all?**

p. 45

•"tolerance of discrete passive components, offset added by active components, OpAmps' SNR, etc." **what is the tolerance, the offset, and SNR (signal-to-noise ratio? Should be defined?)**
•"pasive components" **passive?**
•"either higher or smaller than" **higher or lower, or bigger or smaller?**
•"different gain values due to the the tolerance"

p. 46

•"As a consequence, the speed of the readout process is limited greatly by the analog settling time. In any case, the digital signal delay is a parameter that must be taken into account in the timing constraints in the firmware design." **Why must the delay of the digital signal be taken into account if it is much smaller than the delay of the analog signal?**
•"the delay of rising and falling edge is different" **how do I see that in figure 46?**

p. 47

•"From figure 47 it is visible that the delay of the flag is shaping time-dependent" **because it is asserted at maximum?**
•"After the configuration register is modified," **all the 234 bits?**

p. 49

•"First Hardward Version" **hardware?**

p. 50

•"packaged in 80-pin QFP cases" **what is it?**
•"The LVDS signals, as recommended, have a coupled impedance of 100Ω." **Why recommended?**

p. 51

•"In all the cases, the power supplies showed good performance." **What does it mean specifically?**

p. 52

•"This cable is used as a way of isolation of the ALTERA development kit from the radiation when the system is under testing in a radioactive environment." **The electronics on the PCB with the sensor does not need to be isolated from the radiation?**
•"that let the designer to selectively test the channels" **without to?**
•**why is 1000mV to 1000 5:2?**

p. 54

•figure 56: "Peak voltage per channel for two ASICs (baseline subtracted), using a channel gain of 28. 5 mV/fC and applying a charge of about 47. 5 fC. " **Since 28.5mV/fC×47.5fC=1.353V, and the data are centered at about 1.3V, does it mean that the subtracted baseline is about 0.05V?**
•"this is the baseline implemented in every channel in order to keep the amplifiers in the high gain region. A deeper analysis of the baseline value is provided in later sections. " **Why does this baseline keep the amplifiers in the high gain region? What baseline would put the amplifiers into a low gain region? Or is that the subject of the analysis in later sections?**
p. 55
•"This effect is more evident when the strip capacitances are higher. " **Why? Because the signal to noise ratio is inversely proportional to the total input capacitance?**
p. 56
•"a very useful tool to get familiar with the ASICs and understanding their behaviour. " **To get familiar and understand, or for getting familiar and understanding?**
•"However, the first version is limited by its physical dimensions, number of lines connecting the constituent parts (mainly the HSMC connector), number of USB cables (x2) and external power supplies (x2). Additionally, it is clear that interconnection of the parts by wires means more noise added to the system. " **Why are USB cables and external power supplies multiplied by 2?**
•"Since this system is a mixed signal design, " **mix between analog and digital?**
•"Electro Magenetic Interference" **magnetic?**
•"The best way to counteract this situation is carefully designing a single PCB layout containing all the components and reducing the size and number of external connections of the system; That is the main goal of the second
version of the hardware. " **Lower case after the semicolon? Also elsewhere in the text. More exposure to radiation?**
p. 57
•"bare ASICs were used instead of the packaged versions. " **What is a bare and packaged ASIC?**
•"the connection of the ASIC' s pins to the PCB traces was not done by soldering the pins (as in the first version) but by means of wire-bonds, "**why?**
•"Figure 59 shows a detail of the wire-bonds connecting the ASICs and strip channels to the PCB traces. " **Figure 60?**
p. 59
•"dedicated I/O sma connectors for external clocks, I/O sma connectors for trigger signals, switch for int/ext bias supply, switch for analog signals, and Back Side Pulse Circuit. " **The I/O sma connectors for clocks and for trigger signals are to the left of the FPGA? Where is the switch for the analog signals?**
•"Converter TDC can be used to create a telescope. " **What does that mean?**
•"Figure 61 shows an sketch of the system. " **A?**
p. 60
•"During the design of the second PCB version careful attention was paid to minimize as much as possible the noise levels and the PCB area. " **To minimizing or minimization?**
•"When designing PCBs for systems containing analog and digital signals, or better known as mixed-signal designs it is easy to distort sensitive analog signals by surrounding digital ones or even cause interference among digital signals if the PCB layout is not designed carefully. " **Define mixed signal already on p. 56?**
•"High Desnsity Interconnect HDI PCB" **density?**
•"Figure 62 shows that the output signal of each channel is slightly different, but the differences are smaller when the channels belong to the same ASIC. "**why are ASIC 1 and 2 closer than 3 and 4?**
p. 61
•**precision to four significant digits in figure 63?**
p. 62
•"From figure 63 it is visible that two peaks are produced for the same mono-energetic source, " **why the long tail on the left?**
•"increase the differences channel to channel" **the channel to channel differences? Also elsewhere in the text.**
•**what is the sample in figure 64? How do the values of voltage in figure 64 correspond to the values on the vertical axis in figure 62 and on the horizontal axis in figure 63? The baselines of ASIC 1 and 2 are further away than those of 3 and 4. Is that a contradiction to figure 62?**
•"the system must undergo fundamental equalization and calibration processes before using it in any application. " **Before it is used? Or we must carry out equalization and calibration of the system before using it?**
p. 63
•"The second one is the associated 60MHz clock for a synchronous communication through the FTDI chip (USB). " **Associated to what?**
•"to cope with this two clock domains" **these?**
•"saved in the ASIC' s analog memory" **what is an analog memory?**
p. 64
•"As seen in figure 65, when a clock edge is detected during the readout phase, the PD signal changes from its current value to the next value from the analog memory. " **What is a clock edge? In figures 34-36, the clock signal is periodic.**
•"the readout flag is set every time there is at least one valid event available" **how does the system know which event is valid?**
•"if the flag doesn' t lower after the appropriate waiting time means that there is a new analog value to read" **it means?**
p. 65
• **How does (6) give 36,140 frames per second and 14.1671 MB per second?**

p. 66

•"If the information is about data read from the ASICs, each burst sends information about one single channel." **The information is about the data or is it the data itself?**

•**what causes the branching in figure 69?**

p. 67

•"A custom designed softwawe" **software?**

•"The GUI has three different types of graphs: one type (ASIC1 to ASIC4 graphs) shows the amplitude of the events recorded by the channels of each ASIC independently; a second type shows" **first type, second type? which one is in figure 70? The second?**

•"one (Trim File) contains all the information about the equalization of all the system' s channels and the second one (Config File) contains" **the first one and the second one, or one and the other?**

•"If needed, advanced parameters can be manually changed for special purposes." **Which parameters are advanced?**

p. 68

•"threshold and test DAC scans provide data sampling of every step of the DACs which is important to calculate their real baseline value, as well as their linearity." **They measure the baseline rather than the baseline scan? Linearity of what depending on what?**

•"hence having several enegy points to fit a calibration curve for each channel" **energy? Also in figure 69.**

•"Since the test pulse circuit of every ASIC is slightly different, it must be characterised very deeply," **what does it mean to characterize deeply?**

•"This is important in order to monitor the temperature of the sensor and ASICs during any measurement." **Why?**

p. 69

•"The baseline scan is the first step in the characterization of the system, and in order to minimize the situation previously described," **minimize the problems? Also elsewhere in the text.**

•"it must be excecuted for all the channels" **executed?**

•"In the ASIC, every channel contains a baseline voltage on which all the incoming signals are referenced to," **no on?**

p. 70

•**why is the mean and the RMS different in figure 72 from figure 64?**

p. 71

•"the same or simmilar minimum amount of energy." **Similar?**

•"the channel with the highest standard deviation (σ) when counting all four ASICs." **Considering or comparing?**

p. 72

•"As shown in figure 74, the threshold is placed at 6σ above the baseline of the channel with the highest noise level." **Or with the highest baseline? Cf. on the next page** "the global threshold of each ASIC can be calculated as the sum of its highest baseline plus 6σ" **Where did the value of sigma came from in here?**

p. 73

•"As previously described in the section 7.2," **in section?**

•"After the full equalization of the system was completed, the threshold value of the system was set to approximately 3 keV" **where did this value come from?**

p. 74

•"where Vshift represents positive or negative offset added to the signal." **Is Vshift in figure 76 positive even though the voltage level goes down?**

p. 75

•**perhaps better layout of equations (12) and (13) which could be aided by shorter symbols for the quantities.**

•"Then the calibration can be focus only in the real gain of each channel." **On? Also elsewhere in the text.**

p. 76

•"Calibration is an important part of the characterization of any electronic device intended to measure physical variables, and in the case of strip sensors it is not an exception." **...and the case of strip sensors is no exception?**

•"The result is a system that behaves slightly different according to the position on the sensor" **differently? Depending on?**

•"The way to accomplish a uniform behaviour of the system implies a deep understanding of the individual characteristics of each channel, and that is done comparing the performance of every channel when interacting with the same amount of charge/energy." **Requires a deep understanding? By comparing?**

•"The energy of each channel is measured as an amount equivalent to the peak amplitude of the channels' output" **channel's?**

p. 77

•"The problem is even worse if we take into account that the system uses four ASICs for a single strip sensor" **worse because the system uses?**

•"it is necessary to choose the combination that can offer better results" **the best?**

•"The second method is more comfortable" **suitable? Also elsewhere in the text.**

p. 78

•"The inconvenient of this method, as stated before, is" **drawback?**

•"Additionally, it is well known in XRF that the energy of the photons is always lower than the energy of the X-rays" **the fluorescence photons? The X-rays are made out of photons as well. What fluoresces? The detector?**

•**in (14) what is DAC and why 5 in the denominator?**

•"a Gaussian distribution of the output values can be obtained" **output voltage values?**

•"elseways curves must be used to model their behaviour." **Otherwise?**

p. 79

•what does Mean and RMS mean in figure 78 if different values are plotted rather than a distribution of one value?

p. 80

•"Additionally, the baselines of the test DACs are not always similar and their values can be different from the theoretical one." What is the theoretical baseline and where does it come from? From the maker?

•in figure 79, the measured result is wrong by about a factor of 4 between about 15keV and about 60keV. Does it mean that the slopes in figure 78 are wrong by a factor of four, although the differences between the slopes are much smaller? Is there a systematic error in the slopes?

p. 81

•what is what in Figure 80?

p. 83

•"The X-ray fluorescence photons were obtained from Zirconium (15.74 keV), Molybdenum (17.44 keV) and Indium (24.14 keV)," what is the X-ray source for the XRF? Lower case for the names of the elements? Also elsewhere in the text.

•"This is the case of the gamma photon source, which activity is 1.7 GBq." Whose activity?

•"After cumulating enough statistics in each channel," accumulating?

p. 84

•why no numbers on the vertical axis in figure 84? Is it just a schematic?

p. 85

•is there any justification for the form in equation 16, or is it just what fits? What makes the function either growing or decaying, i.e. what sets the sign of b?

•what are the quantities in equation 17?

p. 86

•what is the meaning of the Mean and the RMS in figures 86 and 87 if these are data for different elements? Should be done for each element separately?

p. 87

•"In the case of the gamma photons from 241Am, due to the high activity of the source, it is possible to see not only the more intense peak (59.54 keV) but also less intense peaks as 26.4 keV or 17.8 keV." Peak at? And also at about 5 and 2 keV?

•"When measuring XRF from Indium, a second peak appears at lower energies (left peak). This second peak is not caused by the system itself but instead it was produced by secondary particles. The reason why the measurement of the Indium peak was notably more affected by the Lead fluorescences is because of the small size of the indium target used."

The secondary particles are lead fluorescence? Why should lead influence more a smaller target than a larger target?

p. 91

•on the top horizontal axis energies of the emitted alpha particles by the three elements?

p. 94

•"strip detectors are much cheaper than pixel detectors as long as the ASIC's size and design are not limited by the pixel size" because?

•"Besides, the micrometric and complex bump-bonding precess is not needed," process? why not?

•"These procedures showed a remarkable enhancement of the energy spectrum," enhancement of precision?

Posudek dizertační práce

Ing. Yesid Mora Sierra, M.Sc.

Advanced FPGA-based readout electronics for strip detectors

a) zhodnocení významu dizertační práce pro obor

Dizertační práce se zabývá vývojem a kalibrací elektronického systému pro čtení informací ze stripového detektoru. Stripové detektory mají oproti pixelovým detektorům obrovskou výhodu, že vyčítací elektronika nemusí být v bezprostřední blízkosti detektoru a tak je možné ji lépe chránit vůči účinkům záření, které pro ni může být silně degradující. Dizertant vyvinul a oživil elektronické obvody pro vyčítání informací ze stripového detektoru včetně vyhodnocení energie dopadajícího záření. Vytvořil příslušné hardwarové obvody, software pro řídící FPGA i software pro PC, které shromažďuje a vyhodnocuje přijatá data. Velmi významná je v dané aplikaci možnost vyhodnocení energie dopadajícího záření, což při použití stripových detektorů není standardní záležitost.

b) vyjádření k postupu řešení problému, použitým metodám a splnění vytčeného cíle

Doktorand přistupoval systematicky k řešení problému, nalezl podpůrné ASIC obvody (původ Brookhaven National Laboratory) pro vyčítání informací ze stripových detektorů, zaintegroval je do svého návrhu elektroniky. Řízení vyčítání informací z detektoru řídí pomocí FPGA pole. Získaná data přenáší do PC, kde je dále zpracovává. Dizertant rovněž navrhl a provedl energetickou kalibraci celého systému v širokém pásmu energií od jednotek keV do jednotek MeV. Doktorand splnil cíle dizertační práce.

c) stanovisko k výsledkům dizertační práce a k původnímu konkrétnímu přínosu předkladatele dizertační práce

Doktorand vytvořil výše zmíněnou elektroniku pro vyčítání informací ze stripového detektoru a vytvořil software pro řídící FPGA pole a PC, které přijímá a vyhodnocuje změřené informace. Z textu práce mi není zcela zřejmé, co skutečně doktorand sám vytvořil a co nějakým způsobem získal „od třetí strany". V práci například nejsou vůbec publikovány použité nástroje pro tvorbu plošných spojů, přípravu podkladů pro FPGA i software pro PC. Proto mé otázky v posudku budou tímto směrem orientovány.

d) vyjádření k systematice, přehlednosti, formální úpravě a jazykové úrovni dizertační práce

Předloženou dizertační práce byla vypracována systematicky a přehledně, nalezl jsem minimum překlepů. Výtky mám k rešerši, kde některé části (zejména v oblasti stripových detektorů) nejsou ideálně vysvětleny, dále k obrázkům (zejména snímky z osciloskopů, ale nejen ony), které jsou nečitelné, bylo by vhodné použít buď větší velikost obrázků, případně větší fonty, jiné barvy. Rovněž popisy grafů nejsou úplně vhodné, ne úplně vhodná volba jednotek, pak násobící koeficienty. Nalezl jsem některé nesrovnalosti v blokovém schématu elektronického obvodu ASIC (např. chybějící signály PD a OA dále používané v textu) a dále chybějící zkratky v seznamu (např. BSP, XRF). Dále u některých rovnic postrádám odvození a bude to opět v mých dotazech k dizertační práci.

e) vyjádření k publikacím studenta

Doktorand uvádí 10 impaktovaných publikací, kde je spoluautorem, 7 příspěvků z konferencí, kde je hlavním autorem nebo spoluautorem, dále jednu vyzvanou přednášku. Většina publikací se bohužel netýká stripových ale pixelových detektorů. Dle mého názoru je publikační činnost doktoranda na odpovídající úrovni. Doktorandovi doporučuji opublikovat dosažené výsledky v oblasti stripových detektorů v impaktovaném časopise.

f) jednoznačné vyjádření oponenta, zda doporučuje nebo nedoporučuje nebo nedoporučuje dizertační práci k obhajobě.

V případě odpovídajícího zodpovězení mých otázek doporučuji předkládanou dizertační práci k obhajobě.

Otázky:

1. Návrh plošného spoje, FPGA a software pro PC jste vytvořil sám? Jaké nástroje jste pro to použil?
2. Odvoďte rovnice č. 17 a č. 18 z dizertační práce.

Západočeská univerzita v Plzni
Doručeno: 26.07.2019
ZCU 019108/2019
listy: 4 přílohy:
druh:
zcupes12257a9

V Praze, dne 21. 7. 2019

doc. Ing. Martin Kropík, CSc.
Katedra jaderných reaktorů
FJFI ČVUT v Praze